

# **ENVIRONMENTAL PROTECTION IS ACCELERATING DEVELOPMENT OF CLEAN FOSSIL ENERGY IN CHINA'S ELECTRIC POWER INDUSTRY**

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## **INTRODUCTION**

This paper discusses the development of China's electric power industry and briefly reviews the composition of thermal power plants and the status of environmental protection regulations in China. Finally, these regulations and the demonstration projects on clean-coal power generation are discussed.

## **1) DEVELOPMENT OF CHINA'S ELECTRIC POWER INDUSTRY**

China started electric power development as early as 1882, when the first power enterprise, Shanghai Electric Company, was established in Shanghai with a generating capacity of 12 kilowatts (kW), or 16 horsepower. By the end of 1998 and 1999, the total installed generating capacity in the mainland of China amounted to 277 gigawatts (GW) and 294 GW, respectively. Over the past 116 years, development of the electric power industry in China could be divided into 3 periods:

Over the first period of 67 years, from 1882 to 1949, total installed generating capacity reached 1.85 GW, with a total electricity production of 4.31 terawatt hours (TWh) in 1949, which ranked 21<sup>st</sup> and 25<sup>th</sup> in the world, respectively. The largest hydropower and thermal power units were 65 MW and 50 MW, respectively. The Guishan hydropower plant in Chinese Taipei was in operation in 1905. During this period, all equipment for power generation had to be imported and there were no power generating manufacturers in China. The coal consumption rate was as high as 1800 to 2000 grams per kilowatt-hour (g/kWh), and no power networks were established because of the disparate frequency and voltage of power generating systems.

Over the second period of 30 years, from 1950 to 1979, total installed generating capacity reached 63 GW, with an electricity production of 282 TWh in 1979. The largest hydropower and thermal power units were 260 MW and 300 MW, respectively. Three manufacturing bases for power equipment were established and China basically had self-developed its own power industry with the capability of manufacturing 300-MW units.

Over the third period of 20 years, from 1980 to 1999, China's power industry experienced continuous rapid development owing to the fundamental reform policy of opening up to the outside. From a total installed generating capacity of 63 GW in early 1980, total installed capacity by the end of 1999 had reached 294 GW, with an electricity

production of 1230 TWh, both of which ranked second in the world. Over the past 20 years, China's total installed generating capacity increased by 230 GW with an annual increase of 11.5 GW. Currently, supply and demand in the power market is basically balanced. China has the ability to design and manufacture 300- to 600-MW subcritical units and the components of 900-MW supercritical units as well as 1000-MW nuclear units.

The State Power Corporation of China (SPCC) is currently responsible for the operation of national power networks, and around 50% of China's power plants belong to its property and holding companies.

## **2) COMPOSITION OF POWER GENERATING UNITS AND CURRENT STATUS OF ENVIRONMENTAL PROTECTION**

### **Power Generating Units**

Thermal power units currently dominate power generation in mainland China's power industry. In 1998, the installed thermal power-generating capacity accounted for 75.7% of the total capacity of 210 GW, with electricity production by thermal power units accounting for 81.1% of that, followed by hydropower at 17.7% and nuclear power at 1.2%. The proportion of thermal power in total capacity is likely to remain more than 60% for the next 20 to 30 years.

The installed capacity of coal-fired power-generating units currently accounts for more than 95% of all installed thermal power capacity. Raw coal of 470 million metric tons (Mt) and fuel oil of 11.39 Mt were used for power generation in 1998. The fuel oil was mainly used for boiler start-up and low-load operation to maintain flame stability, with very little for oil-fired boilers and gas-turbine units. The problems encountered in coal-fired power-generating units create a bottleneck for sustainable development of China's power industry.

Large, medium and small units coexist, with 37% of total capacity generated by units of 300 MW or more, and 32.5% generated by units of 100 MW or less. In 1998, the average coal consumption rate of thermal power units was as high as 404 g/kWh because of the large proportion of small units.

In order to improve the composition of thermal power units, newly built units will mainly be sized at 300 MW and 600 MW. The 800-MW units were in operation at the end of 1998, and the 900-MW units are now under construction. Meanwhile, the small condensing units (rated 50 MW or less) will be shut down gradually within 5 years. From 1998 to 2004, the SPCC planned to shut down small units producing 14 GW. This will gradually increase the proportion of large units and greatly reduce the rate of coal consumption. Furthermore, the average capacity of gas- and oil-fired combined units has been increasing in recent years, improving both network peak-power regulating flexibility and environmental protection.

### **Status of Pollutant Emissions from Thermal Power Plants**

Environmental protection is one of China's basic national policies. As a developing economy, however, controls on thermal power plants and regulations on emissions of SO<sub>2</sub> and NO<sub>x</sub> are not so stringent, and need certain periods for sustainable development. Poor quality coals and unwashed raw coals constitute the bulk of coal used for power generation in China. Coals used for power generation have an average sulfur content of

1.03% and an average ash content of 25%. Coals with sulfur content as high as 3– 4% are also used for some power plants in Sichuan, Guizhou, Guangxi, and Shaanxi provinces.

This has caused serious regional pollution.

Flue-gas SO<sub>2</sub> removal for power plants is still in the early stages of development. Several demonstration projects for typical SO<sub>2</sub> removal processes have been established, but most power plants have not installed SO<sub>2</sub> removal systems. SO<sub>2</sub> emissions reached 5.29 Mt in 1997 from power plants operated by the SPCC; this accounted for 22.5% of total SO<sub>2</sub> emissions from industry in China.

China's current regulations on thermal power plants control NO<sub>x</sub> emissions at levels below 650mg/m<sup>3</sup>. Annual NO<sub>x</sub> emissions have reached around 3.1 Mt. Large units in recent years have been equipped with low-NO<sub>x</sub> burners, while medium and small units have been retrofitted with different NO<sub>x</sub> control measures. NO<sub>x</sub> emissions from bituminous coal-fired boilers can be controlled below 650mg/m<sup>3</sup> with tangential-firing systems and below 450mg/m<sup>3</sup> with wall-firing systems. NO<sub>x</sub> emissions for anthracite and lean (meager) coal-fired units are much higher.

Emission of dust particulates from thermal power plants has been effectively controlled at 2.5 Mt annually, with an average dust removal efficiency of 96.8%. All newly built thermal power units rated 200 MW or more have been equipped with electrostatic precipitators (ESP) that operate at more than 99% efficiency. Particulate emissions were mainly from units with Venturi water-film dust-removal systems with 80-90% efficiency. Thermal power units rated 100 MW or more with water-film dust removal systems have been retrofitted with high efficiency ESP. In addition to the shutdown of some small units, particulate emissions will be controlled at 1995 levels by 2000.

Comprehensive utilization of coal ash is a must during the design of new units. The total annual discharge of ash from power plants has reached 105 Mt, of which 56 Mt has been comprehensively utilized; this accounts for 44% of total ash discharged and ranks first in the world in ash utilization.

### **3) ENVIRONMENTAL LAWS AND REGULATIONS, AND TARGETS FOR POLLUTANT EMISSIONS CONTROL**

#### **Laws and Regulations on Environmental Protection**

- 1) The "Law of Environmental Protection in PR China (for trial implementation)" was formulated in 1979.
- 2) "Proposals for acid rain control" were issued in 1990.
- 3) "Pollutant emissions standards for coal-fired power plants" went into effect on August 1, 1992.
- 4) The newly revised "Law of Pollutant Emissions Control in PR China" went into effect on August 29, 1995;
- 5) "Pollutant Emission Standards for Thermal Power Plants," the newly revised national standards, were issued on March 7, 1996;
- 6) Regulations on total SO<sub>2</sub> emissions were implemented in 1996, and the State Council ratified a national control plan for total main pollutant emissions over the ninth five-year period
- 7) The control zones for acid rain and SO<sub>2</sub> emissions were specified in 1998. The more stringent regulations on emissions in the two control zones will be implemented.

### **Status of the Environment in 1998**

Major pollutant emissions are SO<sub>2</sub> and dust particulates from coal combustion.

In China in 1998, total SO<sub>2</sub> and dust particulate emissions were 20.9 Mt and 14.5 Mt, respectively, reduced 7.8% and 7.7% compared with emissions in 1997. Industry released 15.9 Mt of SO<sub>2</sub>, accounting for 76.2% of total SO<sub>2</sub> emissions, and SO<sub>2</sub> emissions from power generation accounted for 35% of the total SO<sub>2</sub> emissions. Dust particulates from industry and power generation were 11.75 Mt and 2.5 Mt, respectively, accounting for 80.9% and 17.2% of all dust particulate emissions.

30% of China was covered by acid rain mainly caused by coal combustion; these areas were distributed mainly in the southeast, and in the eastern part of northeast China, with key acid-rain control zones centralized in southern China within the middle and downstream portions of the Yangtze River.

Air quality in Chinese cities is seriously polluted. Pollution in northern Chinese cities is much heavier than that in southern cities. Coal combustion and vehicle exhaust have caused mixed pollution in some large and medium cities. Actual monitoring results of total suspended dust, SO<sub>2</sub> and NO<sub>x</sub> shows that air quality exceeds grade 3 in 43.5% of cities. Both annual and daily average concentrations of SO<sub>2</sub> emissions exceed grade 3 in 62.3% of cities.

### **Division of Acid Rain and SO<sub>2</sub> Control Zones**

The areas seriously polluted by acid rain and SO<sub>2</sub> emissions are classified as acid rain and SO<sub>2</sub> control zones ("the control zones"). The control zones specified in 1998 represented only 8.4% and 3% respectively of the total area in China, yet the SO<sub>2</sub> emissions within the zones accounted for around 60% of all SO<sub>2</sub> emissions in China. Therefore, acid rain and SO<sub>2</sub> emissions in China basically can be brought under control through measures focused on only 11.4% of the economy's land area.

Targets for the control zones in 2000 are:

- acid rain is controlled below the level at the end of 1995;
- SO<sub>2</sub> concentrations in key and class-one cities comply with national environmental standards;
- SO<sub>2</sub> emissions from industry comply with national standards; and,
- national annual total SO<sub>2</sub> emissions are controlled below 24.6 Mt

Targets for the control zones in 2010 are:

- areas within acid rain control zones with precipitation pH values less than 4.5 and 5.6 are reduced, respectively, by 10 to 20% and 5 to 10% compared with the values in 1995;
- SO<sub>2</sub> emissions within the control zones are controlled below the level for the year 2000, and annual total SO<sub>2</sub> emissions are controlled below 20.69 Mt; and,
- SO<sub>2</sub> concentrations in all cities within the two control zones comply with national standards.

Targets for the control zones in 2020 are:

- areas within acid rain control zones with precipitation pH values less than 5.6 are reduced by 20 to 30%;
- SO<sub>2</sub> concentrations in all cities in China meet national environmental standards; and,

- national annual total SO<sub>2</sub> emissions, which would reach 38.0 Mt without controls, are controlled below 16.19 Mt

Measures to be taken for environmental protection are:

- China now produces 90 Mt of coal each year that has a sulfur content of more than 3%, representing 7% of total coal production in China. The mining and utilization of coals with high sulfur content is to be limited. New coal mines with sulfur content of more than 3% have been prohibited since January 1, 1998.
- Control measures for total SO<sub>2</sub> emissions, especially within the two control zones, will be focused on thermal power plants. Except for the cogeneration units, new coal-fired plants have been prohibited within the control zones since January 1, 1998. Within the control zones, newly built power plants firing coals with sulfur content of more than 1% have to be equipped with SO<sub>2</sub> removal systems. SO<sub>2</sub> reduction measures must be taken by the year 2000 for existing power plants firing coals with sulfur content of more than 1%. Fees for SO<sub>2</sub> emissions will be charged to force the power companies to take SO<sub>2</sub> reduction measures.

#### **4) ADJUSTING CHINA'S POWER STRUCTURE FOR ENVIRONMENTAL PROTECTION**

Coal dominates as China's primary energy resource, and its combustion can cause both serious air pollution and greenhouse gas emissions. It is projected that CO<sub>2</sub> emissions in China will exceed those in America in 2020. Therefore, the basic choices for China over the next decades will be to adjust its power structure and develop clean, high-efficiency power generation technologies.

The status of China's current power markets indicates that supply and demand will be balanced in the next few years. The available hours of units will be reduced even though the spare capacity of power networks is increased. Construction of conventional thermal power plants will be limited, and a large number of small units (rated 50 MW each or less) will be shut down within 3 years.

The following steps will be taken to adjust the power structure:

##### **Optimize thermal power structure**

For the next 20 to 30 years, power generation will be dominated in China by thermal power units, which account for around 60% of total installed capacity. Optimizing this thermal power structure should take into account both energy savings and environmental protection.

##### **Shut down small units**

The capacity of thermal power units rated 100 MW or less accounts for 1/3 of total installed thermal power capacity; among these units are 2700 units rated between 6 and 100 MW. By the year 2004, units rated 50 MW or less (producing approximately 30 GW) will be shutdown, and of these, 14 GW will be shutdown by the SPCC.

##### **Develop large thermal units with high initial parameters**

Based on the experiences of manufacturing 300-MW and 600-MW subcritical-parameter units, supercritical-parameter units will be developed through technology importation and cooperative manufacturing until gradually domestic mass production is realized. The size of the first domestically manufactured supercritical unit will be 600 MW, while a 1000-

MW ultra-supercritical unit will also be considered. A demonstration plant with supercritical parameters may be built if necessary.

#### **Develop clean coal technologies**

The most promising clean-coal power technologies in the 21<sup>st</sup> century are circulating fluidized bed combustion (CFBC), pressurized fluidized bed combustion (PFBC), and integrated gasification combined cycle (IGCC). China plans to widely develop clean-coal technologies (CCT) for power generation, and several demonstration CCT plants are now under construction.

#### **Rehabilitate old units**

Rehabilitation of old units will mainly be focused on turbine flow path of 125-MW and 200-MW units, as well as old 300-MW boilers.

#### **Develop Natural-gas-fired combined units**

Currently, the installed gas-turbine capacity is 7.2 GW with small unit sizes. It is imperative to develop natural-gas-fired combined units along coastal areas. This is the key measure to adjusting power structure, improving the environment and achieving flexibility in peak power regulation.

#### **Develop central heating and distributed cogeneration units to improve energy utilization efficiency**

### **Hydropower**

China's available hydropower is projected to be 380 GW, which ranks first in the world and accounts for 16.7% of the world's total available hydropower. To date, only 17% of China's available hydropower has been utilized for power generation. It is estimated that the installed hydropower capacity will reach 75 GW, 95 GW and 150 GW, and account for 24%, 27%, and 28%, respectively, of total installed generating capacity in China by the years 2000, 2005, and 2015. By the end of 2015, utilization of hydropower will reach around 40% of available hydropower in China. Therefore, China will increase investments in hydropower construction as much as possible to reduce dependence on coals.

### **Nuclear Power**

Although China has rich coal and hydropower resources, its average primary energy resources per person are far below the world average. In addition, more than 70% of coal resources are in the northern and western parts of China, while around 80% of available hydropower is in southwest China. In order to solve problems of regional energy shortages, as well as environmental pollution and busy transportation caused by extensive utilization of coal, it is rational to develop nuclear power along coastal areas in southeast China to assist in sustainable development of the electric power industry. To date, 3 nuclear units rated 210 MW each have been in operation, and 8 nuclear units rated 660 MW each are under construction. It is projected that installed nuclear power capacity will reach 8.7 GW and 25 GW by the end of years 2005 and 2020, respectively.

### **Renewable Energy for Power Generation**

China has 253 GW of available wind-power resources. Because of high investment costs for wind-power units, installed capacity is only 230 MW, but this is projected to reach 1000 MW by the year 2005. Solar, geothermal and ocean energy for power generation also will undergo continual trials and tests.

## **5) IMPLEMENTATION OF CLEAN COAL POWER GENERATION**

To implement its strategy for sustainable electric power development, China's former Ministry of Electric Power in 1994 chose clean-coal power generation as one of its directing projects into the 21<sup>st</sup> century; now it is time to complete this implementation. It is unique for a developing country to establish and operate several different CCT demonstration projects during this period of implementation.

### **Developing SO<sub>2</sub> removal process for conventional thermal units and low NO<sub>x</sub> combustion systems**

Environmental protection will be focused on reduction of SO<sub>2</sub> emissions. Approximately 20 GW of existing units need to be retrofitted with SO<sub>2</sub> removal systems. Several typical SO<sub>2</sub> removal systems have been demonstrated, and some proven processes are already in use. Wet FGD systems will be employed mainly for large units. Meanwhile, furnace-sorbent-injection, spray-dryer, sea-water and CFB processes for SO<sub>2</sub> removal also will be developed to meet different requirements.

NO<sub>x</sub> is the major source of acid rain and pollutant emissions in China, where current standards for NO<sub>x</sub> emissions are not so stringent. NO<sub>x</sub> control measures are required to meet not only current standards but also long-term development. At present, the primary control measure is low-NO<sub>x</sub> combustion technologies, but a cost-effective de-nitration process needs to be studied to prepare for long-term development.

### **Developing large supercritical units**

Currently, China has 6 GW of supercritical units in operation or under construction, and 6.6 GW of supercritical units in preparation. All the supercritical units are imported. Only through international cooperation and domestic manufacture can China progress from subcritical to supercritical units. The 2x600-MW supercritical units to be built at Qinbei Power Plant in Henan Province have been approved by the State Planning Commission. China's domestically manufactured supercritical units will be 600 MW in size, and will substitute gradually for 600-MW subcritical units. The 1000-MW supercritical units and ultra-supercritical units also will be developed. As much as possible, the installed capacity of supercritical units will represent a large proportion of total installed capacity within a short period. This will enable a great reduction in the average rate of coal consumption by thermal power units.

### **Developing CFBC boilers**

CFBC boilers have the advantage of firing a wide range of fuels. In addition, reduction of SO<sub>2</sub> and NO<sub>x</sub> formations takes place during coal combustion in the boilers, making them especially suitable for combustion of anthracite and lean (meager) coals from southwestern and northwestern China. These coals are characterized by low volatile matter, low ash fusibilities, and high ash and sulfur contents. China's domestic development of CFBC units will start with 100-MW units to be used mainly for retrofitting of existing and newly built cogeneration units. Then the 300-MW CFBC units will be further developed. A 300-MW CFBC demonstration unit to be built at Baima power plant in Sichuan Province has been approved by the State Planning Commission. Major equipment for the first CFBC plant, as well as design and manufacturing technology, will be imported in a combination of technology with commercial trade.

After the successful demonstration of this plant, China's CFBC units will be utilized greatly.

#### **Demonstrating an IGCC project**

China began technology feasibility studies for an IGCC demonstration plant in 1994; the SPCC planned to build a 300-MW or 400-MW IGCC demonstration unit at Yantai Power Plant in Shandong Province. The State Planning Commission approved this project in 1999, and bids for the project will be solicited this year. Component design, manufacturing technologies and key equipment will be imported. Digestion of imported technologies is intended to develop competence with supercritical units, and gradually improve the proportion of domestically manufactured components so as to reduce investment costs.

#### **Test project of PFBC-CC**

In 1990, China started construction of a 15-MW PFBC-CC semi-industrial test facility, which was commissioned by the end of 1999. One 140-MW PFBC-CC commercial test unit has been planned to be built at the Taishan Plant in Dalian, Liaoning Province, and another at the Jiawang Plant in Xuzhou, Jiangsu Province. The State Planning Commission has approved the projects, technical negotiations with foreign suppliers are underway, and it is expected to make a final decision this year.

China's primary energy resource is coal, and although power generation with coal will remain unchanged for the next 50 years, great efforts have to be made to adjust the nation's power structure for sustainable electric power development and environmental protection. Developing new ways of clean and high-efficiency utilization of coal for power generation is a long-term strategy.